On the Origin of certain Lines in the Spectrum of ε Orionis (Alnitam).

By Sir NORMAN LOCKYER, K.C.B., F.R.S., F. E. BAXANDALL, A.R.C.Sc., and C. P. BUTLER, A.R.C.Sc., F.R.A.S., F.R.P.S.

(Received May 15,—Read June 17, 1909.)

[PLATE 2.]

Although the great majority of the lines in the spectrum of ε Orionis—which is the type-star of the Alnitamian Group of the Kensington Classification—have previously been traced to their source, there remained a few outstanding lines for which no satisfactory origin has been suggested. Recent research here has revealed what appear to be, with little or no doubt, the laboratory equivalents of these lines, whose approximate wave-lengths are 4097·4, 4379·8, and $\begin{cases} 4647{\cdot}6 \\ 4650{\cdot}8 \end{cases}$, the latter being a close double, the mean position of which falls very near the strong oxygen line 4649·3. The first of these lines was given in previous publications* as being probably due to silicium, forming with lines at 4089·1, 4116·4, what were described as the Group IV lines of that element. In a later publication by Mr. Lunt,† although the last mentioned lines were confirmed by him as being high temperature silicium lines, he concluded that the line 4097 could not be ascribed to Si, as he had found no trace of such a line in any of his silicium photographs. The results now arrived at here show that his conclusions were correct, this line having been traced to another origin.

In the course of an inter-comparison of the spark spectra of various metals, a set of four lines of peculiar behaviour was noticed by one of us in the spark spectrum of chromium. These appeared as "pole" or "beaded" lines near one edge of the spectrum, and are shown in strip 10 of the Plate, where they are indicated by four small arrows. Although the spectrum contained several hundreds of lines, a search for other lines of similar appearance along the same edge of the spectrum failed to reveal any. Here, then, was a set of evidently associated lines—possibly all due to the same element—which occurred specially under the conditions of the vapour surrounding one pole of the spark. It was at once seen that the position of the lines was in the

* 'Roy. Soc. Proc.,' vol. 67, pp. 403—409, October, 1900; 'Roy. Soc. Proc.,' vol. 74, pp. 296—298, October, 1904.

† "The Spectra of Silicon, Fluorine, and Oxygen," 'Annals of Cape Observatory,' vol. 10, p. 153, 1906.

vicinity of Hδ, and the presence of strong lines in this region in the spectrum of ϵ Orionis suggested a careful investigation of the laboratory wave-lengths and a comparison with the wave-lengths of the stellar lines.

As the chromium photograph contained lines of iron and calcium as impurities, several standard lines of these metals were available for use as fiducial lines. Those adopted were 4005·408 (Fe), 4063·759 (Fe), and 4226·904 (Ca). From measures made on these and the "pole" lines, the wave-lengths of the latter were calculated by Hartmann's formula. They resulted as follows:—

4089·04	4103·54
4097·49	4116·29

The first and last of these were so near the wave-lengths of the two strong lines of silicium (Group IV), previously referred to, that a silicium origin at once suggested itself. A comparison of the chromium and silicium spark photographs confirmed this suggestion, the lines in the silicium spark agreeing exactly in position with the outside pair of "pole" lines of the chromium spark.

To establish definitely the occurrence of silicium as an impurity in the chromium, the other groups of silicium lines were looked for in the chromium spectrum. Those of Group II (4128·1, 4131·1) and Group III (4552·8, 4568·0, 4574·9), were unmistakably present. The lines of Group I (3905·8, 4103·2) were doubtfully present, but as these occur more prominently as arc than as spark lines, their possible absence could be understood. It may be said here that the Group II and Group III lines of silicium occur in this spark spectrum of chromium as ordinary lines, and not as lines intensified at one edge of the spectrum similarly to the Group IV lines.

It thus became evident that at least two of the strange quartette (4089 and 4116) could be accounted for as being due to silicium occurring as an impurity in the chromium used.

With regard to the other pair, the stronger line of the two (4097·4) was known to be so near the well-marked line of unknown origin in ϵ Orionis (mentioned at the beginning of this paper) that it was determined to enlarge the stellar spectrum up to the scale of the laboratory spectrum of chromium, and make a direct comparison of the two to see if the stellar and laboratory lines agreed in position. When this was done it was found that the three lines mentioned (4089, 4097, 4116) fitted exactly the three well-marked lines of ϵ Orionis in the neighbourhood of Hδ (see strips 10 and 11 of the Plate). The position of the fourth strange line (4103·5) is so near Hδ that the latter line, being strong and diffuse in the star, probably masks the stellar counterpart of the laboratory line.

Although, then, there appeared to be no doubt as to the identity of the stellar and laboratory lines, it remained to determine the chemical element to which the middle pair of abnormal lines could be attributed.

Search for Origins of Lines 4097·4, 4103·5.

From previous experience we knew that the Group IV lines of silicium—with which the above lines are associated in the chromium spark photograph—show more prominently under vacuum tube conditions than in the ordinary spark spectrum. We determined, therefore, to test various vacuum tubes to see if any of them furnished such a pair of lines. As these lines are in the portion of the spectrum beyond the visual region, it was impossible to watch for their appearance, or, if they occurred in the spectrum, to watch their behaviour while the electrical conditions were being varied. It was known, however, that in the Alnitamian stars there is invariably a strong double line of unknown origin near the strong oxygen line 4649·3. This being well inside the visible region of the spectrum, a careful comparison of the region near this oxygen line was made, using vacuum tubes containing various gases, with the object of determining whether any abnormality or intensification near the oxygen line mentioned was introduced while the spark discharge conditions were being varied.

Using a vacuum tube which contained alcohol vapour, under the low-tension spark condition the oxygen line 4649·3 and other oxygen lines in the same region presented quite their normal appearance. With a strong disruptive spark, however, it was instantly seen that there was a conspicuous intensification in the spectrum at or near 4649, without any corresponding alteration in the intensity of the neighbouring oxygen lines. This appeared so encouraging that it was decided to obtain at once a photographic record of the spectrum for more detailed examination. The resulting photograph—portions of which are reproduced in strips 2 and 16—showed the spectrum under the disruptive spark conditions. As compared with the lines near 4649 as they appear in the normal oxygen spectrum (strip 18), it will be seen that there is a considerable modification in the appearance of the lines in the alcohol spectrum (strip 16), an extra line having appeared on the more refrangible side of the oxygen line 4649·3, and the oxygen line on the less refrangible side, 4650·8, being considerably strengthened, probably by the superposition of another strange line.

These strange lines will be referred to in detail in a later part of the paper, and their relation to ϵ Orionis lines discussed.

An examination of the alcohol photograph in the region near λ 4100 showed at once an outstanding pair of lines at λ 4097·4, 4103·5, which,

when directly compared with the pole lines of the chromium spark photograph, was found to agree exactly with the middle pair, the origin of which was under investigation. The alcohol spectrum contained, in addition to oxygen, hydrogen, and carbon lines, the strange lines referred to, and the ordinary lines of nitrogen. These latter may have been introduced by a slight leakage of air into the tube. A comparison of the alcohol photograph with various photographs of oxygen, carbon oxides, and hydrogen spectra, failed to show on the latter any lines corresponding to the pair under investigation. It was found, however, that a pair of lines corresponding exactly in position with the strange double existed in the ordinary spark spectrum of nitrogen, the components being of the same relative intensity, but the double in the nitrogen being quite insignificant in intrinsic intensity as compared with its appearance in the alcohol tube. This, then, tended to show that the lines were due to nitrogen, but under certain conditions of current were abnormally strengthened, relatively to other nitrogen lines.

Photographs were then taken of the spectra given by a nitrogen vacuum tube (Gallenkamp)—

(1) Using the large jar and large air-break.
(2) „ small „ small „

These spectra are respectively shown in strips 3, 5. Under the low-tension condition, although the strong nitrogen line 3995 of the ordinary spark spectrum is shown as a strong line, the double 4097—4103 is lacking. Under the high-tension condition, however, the latter double is very conspicuous, the stronger of the pair being now quite as strong as, if not stronger than, the nitrogen line 3995. The nitrogen tube spectrum of strip 3 shows the stronger oxygen lines. (Note the triplet 4070—4076.) Strip 4, however, shows the nitrogen vacuum tube spectrum without any trace of oxygen, but still showing the abnormal double 4097·4—4103·5.

The following table shows the intensities of the ordinary strong nitrogen line 3995·1, and the abnormal lines 4097·4—4103·5 as they occur in the

λ.	Exner and Haschek.	Kensington spectra.		
	Spark spectrum. Max. int. 50.	Normal spark at atmospheric pressure. Max. int. 10.	Vacuum tube. Low tension. Max. int. 10.	Vacuum tube. High tension. Max. int. 10.
3995·1	50	10	8	10
4097·4	3	4	—	10
4103·5	3	2	—	7

normal spark spectrum of nitrogen, and as a comparison the relative intensities are given of the same lines in the Kensington vacuum tube photographs referred to and reproduced in the plate.

During the search for the origins of the pair of lines 4097—4103 the spectrum given by an amidogene vacuum tube was photographed. This was found to contain four lines which correspond exactly in position with the four "pole" lines of the chromium spark. A portion of this amidogene spectrum is reproduced in strip 12. Reference to this and strips 10 (chromium), 11 (ϵ Orionis), and 13 (nitrogen high tension spark), will show that the three lines 4089, 4097, and 4116 of the amidogene and chromium spectra are identical with three very prominent lines of ϵ Orionis, the fourth line 4103 being probably masked in the star by the adjacent strong $H\delta$ line. The middle pair of the amidogene (strip 12) and chromium (strip 10) quartette is also seen to be identical with the strongly developed pair of the nitrogen spectrum of strip 13. The presence of the two silicium lines 4089·1 and 4116·4 in the amidogene spectrum is probably accounted for by the presence of small detached particles of glass in the bore of the capillary of the vacuum tube, which was an old one.

Reference to Nitrogen Lines in Stellar Spectra.

Shortly after the discovery by Mr. Frank McClean in 1897 of oxygen lines in some of the helium stars, the identity of other lines in similar types of spectra with the stronger spark lines of nitrogen was established by a comparison of the Kensington laboratory and stellar photographs, and these identifications were incorporated in the tabular matter in a Catalogue of 470 of the Brighter Stars.*

In a paper "On the Presence of Oxygen in the Atmospheres of certain Fixed Stars,"† Mr. David Gill, after saying (p. 205): "there remains not the slightest doubt that all the stronger oxygen lines are present in the spectrum of β Crucis, at least between λ 4250 and λ 4575," goes on to say: "It is almost equally certain that there is no trace of true nitrogen lines in this spectrum." In this he was probably referring to the limited region of the spectrum which he investigated. That the strong nitrogen lines 3995·1, 4630·7 occur in the β Crucis spectrum there can be no question, as a reference to Mr. McClean's tabular list of lines‡ and his reproductions will clearly show.

Another line recorded by McClean in β Crucis at λ 4447·2 is doubtless

* Published by the Solar Physics Committee (1902).

† 'Roy. Soc. Proc.,' vol. 65, p. 205, April, 1899.

‡ 'Spectra of Southern Stars,' 1898.

the counterpart of the strong nitrogen line at the same wave-length (Exner and Haschek's λ 4447·23, intensity 20). This line occurs in the region investigated by Gill, but he does not record it in his list of stellar lines.

The wave-length of the line in ϵ Orionis near 4097 as recorded in a previous publication* was 4097·3. The wave-length of the abnormal nitrogen line with which this has now been identified has, from measures made on the Rowland grating photographs of the nitrogen spark, been found to be 4097·45. This is not far removed from the recorded wave-length of the stellar line, but the latter has, with others in the same region, been remeasured, and its position redetermined by use of Hartmann's formula.

The fiducial lines used were 4026·34 (helium), 4143·92 (asterium), and 4388·10 (asterium). The resulting stellar wave-lengths are given in the first column of the following table. The second column gives the wave-lengths of the corresponding lines as reduced from the Rowland grating photographs of the laboratory spectra. The last column gives the origins:—

Stellar wave-length. Reduced from photograph with one 6-inch Henry prism.	Laboratory wave-length. Reduced from Rowland grating photograph.	Origin.
4076·19	4076·08	Oxygen
4089·14	4089·09	Silicium (IV)
4097·59	4097·45	Nitrogen (abnormal)
4116·54	4116·51	Silicium (IV)

Taking into account the fact that the stellar photograph is of comparatively small dispersion there is very good accord in the wave-lengths. The differences between the two sets are within the limits of error in determining the stellar wave-lengths; and there seems no reason to doubt from this evidence that the identity of the stellar and laboratory lines given in the table is a real one.

The wave-length 4096·9 recorded in the Harvard publication† for the ϵ Orionis line appears to be about half a tenth-metre too low. Hartmann,‡ for what is undoubtedly the corresponding line in δ Orionis, gives 4097·49, which is in very good accord with the redetermination of the stellar wave-length (4097·59), and also with the wave-length of the nitrogen line identified with it (4097·45).

* 'Catalogue of 470 of the Brighter Stars,' Solar Physics Committee, 1902.

† "Spectra of Bright Stars," 'Annals. Harv. Coll. Obs.,' vol. 28, Part 1, Table IV p. 53 (1897).

‡ 'Astrophysical Journal,' vol. 19, p. 272, 1904.

In the paper by Mr. J. Lunt,* in which he suggests that the stellar line 4096·9 cannot be ascribed to silicium, he points out that it is a very important stellar line, and gives the following extract from Cannon and Pickering's intensities :—

Wave-length.	Intensities.				
	29 Canis majoris.	τ Canis majoris.	ϵ Orionis.	β Centauri.	γ Orionis.
4089·2	6	12	15	5	2
4096·9	18	6	4	2	1
4101·8	25	25	25	35	40
4116·2	3	6	10	2	0

In a footnote, Lunt says: "The first and last of these are silicon lines. Cannon and Pickering assign no origins." In a subsequent paper,† Miss Cannon ascribes the lines 4089·2 and 4096·9 to argon. These identifications will be discussed in a later part of the present paper.

From the preceding table it will be seen that in the star 29 Canis Majoris line 4096·9 is tremendously strengthened relatively to the silicium lines 4089·2 and 4116·2. In ϵ Orionis, although it is a well-marked line, it is considerably inferior in intensity to the two lines just mentioned.

With reference to the origin of the stellar line 4096·9 (Hartmann's λ 4097·49), Lunt,‡ after saying: "Some other origin than silicium must be sought for this line," goes on to say: "There are both oxygen and nitrogen lines very close to this place, but neither of these elements accounts for the strong stellar line." That the nitrogen line he refers to is a line of abnormal behaviour was not, of course, then known to him, nor to us, and he probably based his opinion as to its non-identity with the stellar line on its insignificant intensity in the ordinary nitrogen spectrum.

It will be instructive to compare the intensities of the strongest *spark* lines of nitrogen, as they occur in various types of stellar spectra, with the intensity of the abnormal nitrogen line 4097·4 in the same types. The following table gives these comparative intensities in the Rigelian, Crucian, and Alnitamian groups of the Kensington classification.

The type-stars of these groups are respectively Rigel, Bellatrix, and ϵ Orionis. It may be said here that no nitrogen lines, either of the normal or abnormal kind, occur in any of the groups representing a lower stage of

* 'Roy. Soc. Proc.,' A, vol. 76, p. 123, February, 1905.

† 'Annals Harv. Coll. Obs.,' vol. 56, part 4, pp. 66, 67.

‡ 'Roy. Soc. Proc.,' A, vol. 76, p. 124, 1905.

temperature than the Rigelian. As the Kensington photographs of stellar spectra include nothing of a higher level than the Alnitamian group, it is impossible to say how the lines of nitrogen behave in the higher groups.

Stellar group.	Nitrogen lines.	
	3995·1 (Normal strong spark line.)	4097·4 (Abnormal line.)
	Intensity, max. 10.	Intensity, max. 10.
Alnitamian (ε Orionis)	1	4
Crucian (γ Orionis)	4	1
Rigelian (β Orionis)	2	—

This table shows that the ordinary spark lines of nitrogen (as represented by the strongest line of that class) come in as weak lines in the Rigelian stars, intensify and obtain their maximum intensity at the Crucian stage, and weaken again at the higher Alnitamian stage. On the other hand, the abnormal nitrogen line 4097·4 is lacking in the Rigelian, occurs as quite a weak line in the Crucian, and has considerably developed at the Alnitamian stage. As shown in a previous table abstracted from Cannon and Pickering's publication, this line becomes more intense still in other stars, having an intensity 6 in τ Canis Majoris, and an intensity of 18 in 29 Canis Majoris. In the latter star it closely approaches the intensity of Hδ (25).

Reference to Argon Lines.

In a recent publication on the 'Classification of Stars by their Photographic Spectra,'* Miss Cannon gives a brief description of each class of spectrum. Under Classes Oe, B, and B1, of which the type-stars are respectively 29 Canis Majoris, ε Orionis, and β Canis Majoris, lines 4089·2 and 4096·9 are referred to as being due to argon. Abundant evidence has been given in previous Kensington publications† that the former line is due to silicium (Group IV), and this has been confirmed by Lunt at the Cape Observatory. The second line is undoubtedly identical with the ε Orionis line which has now been traced to the abnormal nitrogen line 4097·4.

No evidence is given in the Harvard publication on which the identity of these stellar lines with argon lines has been based, and it is difficult to

* 'Annals Harv. Coll. Obs.,' vol. 56, No. 4.

† 'Roy. Soc. Proc.,' vol. 67, pp. 403—409, October, 1900; vol. 74, pp. 296—298, October, 1904.

understand how they have come to be recorded as argon. Reference to Eder and Valenta's publication* on the argon spectrum shows that there are lines at λλ 4089·04, 4097·27. The respective intensities of these, however, are only 1 and 2 where the maximum is 10. As there are, between λλ 3900 and 4700, 114 lines of argon, varying in intensity from 1 to 10, the evidence for the stellar lines being argon is almost negligible unless it can be shown that the stronger argon lines also occur in the stellar spectrum, or, as an alternative, that this pair of weak argon lines has some special behaviour relatively to other argon lines when the laboratory conditions are varied.

To put this alternative to the test, the argon spectrum was photographed under the high-tension spark conditions which produced the abnormal nitrogen lines previously referred to, but there was no evidence of any relative strengthening of the weak argon lines in question.

Comparison has also been made of the wave-lengths of the strongest lines of argon with those of the ε Orionis lines and there appears to be no connection whatever between the two sets.

Line 4379·8.

After the stellar line 4097 had been identified with a nitrogen line of abnormal behaviour, the nitrogen spectrum was examined to see if there was an anomalous line which could account for a fairly well-marked and sharp line in ε Orionis whose wave-length had, from recent measures, been estimated as 4379·8, and whose origin was unknown. In the ordinary spark spectrum of nitrogen there is a line of insignificant intensity agreeing in position with the stellar line. Exner and Haschek's wave-length for this line is 4379·75. Its intensity is 1 as compared with 50 for the strong spark line at 3995·1, and 20 for the strong spark line at 4447·2.

On turning to the spectrum given by the Gallenkamp vacuum tube of nitrogen when the high-tension spark is used, this line was seen to be enormously developed relatively to other nitrogen lines. This is shown in strip 7, where the line in question is quite as strong as 4447·2, whereas in strip 9 although the 4447·2 line is very strong, 4379·8 is lacking.

In another spectrum of the Gallenkamp tube, not reproduced on account of the broad nature of the lines, the line 4379·8 is, without exception, the strongest line in the whole spectrum.

In the light of the existence of the other abnormal nitrogen line 4097·4 in the stellar spectrum, then, there is little doubt that this abnormal line 4379·8 is identical with the stellar line at the same wave-length.

* 'Beiträge zur Photo-chemie und Spectralanalyse,' p. 247, Wien, 1904.

Lines 4647·6—4650·8.

When a strange double in this region was found in the alcohol spectrum (strip 16) which showed the abnormal nitrogen lines previously discussed, no doubt was felt as to its identity with the well-marked unknown double in ϵ Orionis (see strip 14).

Pickering, although he only records the stellar line as single, gives its wave-length as 4649·2, which is very near the wave-length of the oxygen line (4649·27), which falls about midway between the components of the strange double in Kensington laboratory spectra, giving the appearance of an equal-spaced triplet (see strips 16 and 17).

To establish the identity more thoroughly, the wave-lengths of the lines were determined both from the laboratory and stellar photographs. The resulting values are as compared below:—

Stellar wave-lengths.	Laboratory wave-lengths.
4647·6	4647·53
4650·8	4650·92

Taking into consideration the comparatively small dispersion of the stellar spectrum, their wave-lengths are in as good accord as could be expected.

Reference to strips 14 and 16 will show that, although the stellar spectrum is enlarged 12 times, the double given by the alcohol vacuum tube and the stellar double are identical in position. The two oxygen lines 4591 and 4596 are also seen to be in agreement with two weak stellar lines.

Although the identity of the stellar and laboratory doubles had been practically established both by measurement and direct comparison, there was no certainty as to their exact origin. As the alcohol spectrum in which the lines were first noted showed lines of oxygen, carbon, hydrogen, and nitrogen (the latter as impurity lines), it seemed reasonable to assume that the lines in question belonged to one of these elements.

With the object of tracing the lines to a definite origin, the spectra of various vacuum tubes were then investigated both visually and photographically, the same spark conditions being used as in the case of the alcohol tube which gave the lines. The coil used was one which gives an 8-inch spark, and a large jar and large air-break were introduced.

The vacuum tubes investigated were those respectively containing nitrogen, amidogene, oxygen, sulphur-dioxide, coal gas, and carbon bisulphide. The only three of these to reveal the lines were SO_2, CH_4, and CS_2. The fact that neither the oxygen nor nitrogen tubes gave the lines seems to preclude the possibility of their being due to either of these elements. The

SO_2 and CS_2 spectra, in which the double occurs, show no hydrogen lines, so hydrogen could be discarded as furnishing no clue. Sulphur clearly could not be the origin, as there is no trace of the lines of that element in either the alcohol or coal-gas spectra which give the strange double.

This process of elimination left only carbon to be considered. That element could account for the presence of the lines in the alcohol, CS_2, and CH_4 spectra, but not in that of SO_2 if the sulphur dioxide was pure and free from carbon. To test the latter point the strong characteristic line of carbon at 4267·3 was looked for in the SO_2 spectrum, and it was at once seen that it not only occurred there, but was one of the strongest lines in the whole spectrum.

The fact was thus established that in every case where the strange double appeared, the spectrum also contained the strong carbon line 4267·3, and the collective evidence pointed to carbon or some modification of carbon as being the true source of the lines.

It was then determined to investigate the spectra given by the spark between carbon poles in various gases at atmospheric pressure, using exactly similar electrical conditions—with regard to coil, jar capacity, and size of air break—as for the vacuum tube experiments. The first gas tried in this way was oxygen, and although visual observations failed to show the lines with certainty, the photographic record showed that the more refrangible component was present but weak; the less refrangible component, falling on the fairly strong line of oxygen at 4650·8, cannot be separately distinguished.

The spectrum of the carbon spark in nitrogen and ammonia was then tried, but as the visual observations gave no indication of the lines under discussion, no photographs were taken.

The spark in hydrogen was then examined, and it was at once evident that this condition gave the double quite strong and isolated. A photograph of the spectrum was obtained, and the region 4550—4670 of this is reproduced in strip 15, where it will be seen that the double stands alone, there being no oxygen lines mixed up with it, as in the alcohol and SO_2 spectra of strips 16 and 17. The original photograph of the carbon spark spectrum in hydrogen shows, in addition to the double 4647·6, 4650·8, the strong carbon line 4267·3, the hydrogen lines, and a faint trace of the strongest nitrogen line 4630·7. The last named is shown in the Plate; the others are outside the region of spectrum reproduced.

As further evidence of the identity of the stellar and laboratory lines, it may be pointed out that the nature of the double, as seen isolated in strip 15 (carbon spark in hydrogen), is the same as in the stellar spectrum

(in the latter case this point is not so well shown in the reproduction as in the original negative), the more refrangible line 4647·6 being sharp on each edge, while the other component, 4650·8, is sharp on its more refrangible edge, but diffuse towards the red.

The fact that the double occurs strongly in the spectrum of carbon poles in hydrogen, only weakly in that of the same poles in oxygen, and apparently not at all when nitrogen is the gas used, would tend to show that, if really due to carbon, the presence of hydrogen, although not absolutely necessary, is conducive to the production of the lines. It must be borne in mind, however, that the SO_2 vacuum tube gave the lines quite strongly without any trace of hydrogen being present. It may be that, although in the presence of oxygen only along with the carbon the lines are not well developed, the presence of sulphur as an additional element has the same effect on the development of the lines as that of hydrogen.

The bulk of the evidence is certainly in favour of the strange double being due to carbon or some modification of that element, the lines only coming out strongly under particular conditions of current. Even at this stage of the inquiry, however, the evidence is not absolutely conclusive, and a carbon origin must be accepted as only provisional. Further research will probably settle the origin more definitely.

It may be said here that, so far as we are aware, this important double line has not previously been recorded in laboratory spectra, either of carbon or any other element. The reason for this is probably that, in contra-distinction to the carbon line 4267·3, which occurs under a comparatively great range of spark conditions, the new double is of a more fleeting nature, and has probably hitherto eluded the attention of spectroscopists.

Reference to Bright-line-star Spectra.

In a paper on "The Wolf-Rayet Stars,"* Prof. Campbell gives a comparison of the lines in "Bright-line Stars" with those of other types, amongst the latter being Orion stars (dark lines). In this he suggests that the strong line 4652 in stars of the Wolf-Rayet type is identical with the line 4652 of the Orion stars. The line he refers to in the latter case is undoubtedly the strong conspicuous line of ϵ Orionis, which has been found to be a double line in the Kensington spectra (4647·5—4650·9), and which has been shown to be, in all probability, due to carbon, the laboratory lines occurring prominently only under particular conditions of current.

The position of the middle of this double is, from recent Kensington measures of the best ϵ Orionis spectrum, 4649·2, this being also the wave-

* 'Ast. and Ast. Phys.,' vol. 13, p. 473, 1894.

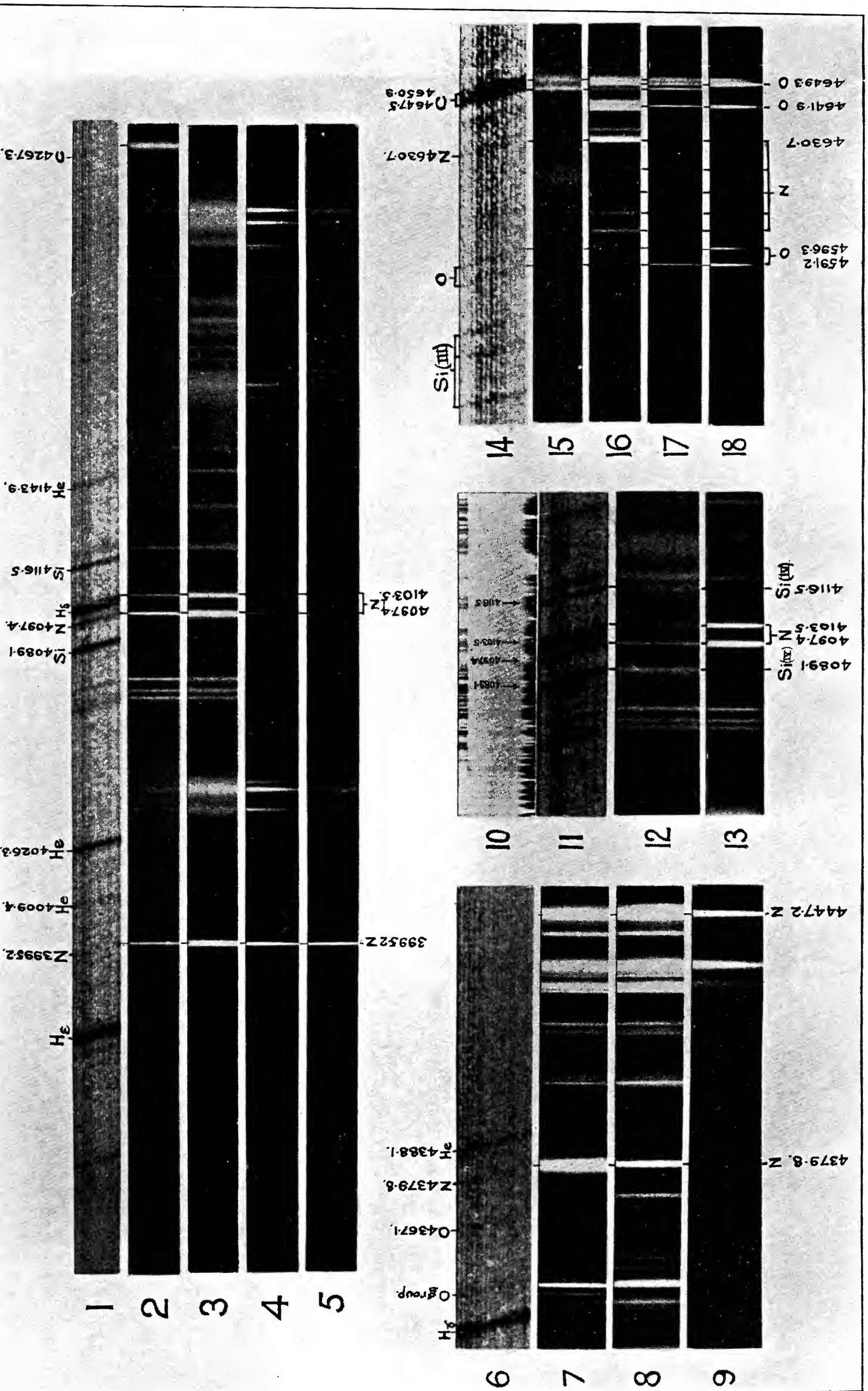
length of the single line recorded by Pickering. If this be really identical with the Wolf-Rayet line, it would appear that Campbell's wave-length for the latter is somewhat high, but the difference is possibly within the limits of error in determining the wave-lengths of such broad, crude lines as those in Wolf-Rayet stars. The line 4652, for instance, is, in γ Argus, of such a width as to cover about 30 tenth-metres.

Possibly the apparent agreement in position of the Wolf-Rayet line and the strong, dark double of ϵ Orionis, is only a fortuitous one, but as these spectra contain other lines in common, such as the stronger helium lines, and proto-hydrogen lines (4686, 4542, 4200), it is suggestive of a real identity.

It seems necessary to obtain, if that be possible, more accurate wave-lengths of the lines in Wolf-Rayet stars before this point as to the identity of the two lines can be definitely settled.

Further research will be made with the object of possibly tracing other conspicuous Wolf-Rayet lines to abnormal lines of known gases.

[*Note added June*, 1909.—Shortly after the above paper was sent in, and before the reading, further experiments were made, giving conclusive evidence that the double line at 4647·6, 4650·8, could be ascribed to carbon. Three spectra were photographed on the same plate, the spark conditions being identical in every case, (1) carbon spark in hydrogen, (2) platinum spark in coal-gas, (3) platinum spark in hydrogen. While the platinum spark in hydrogen shows no trace whatever of the double, the platinum in coal-gas gives it, quite conspicuous and identical in position and nature with the double produced with carbon in hydrogen.]



SPECTRA SHOWING IDENTIFICATION OF HITHERTO UNKNOWN LINES IN ε ORIONIS.

DESCRIPTION OF PLATE 2.

Strip No. 1.—Spectrum of ε Orionis (region 3900—4270). Directly enlarged 7 times.

„ 2.—Spectrum given by alcohol vacuum tube (8″ coil, disruptive spark, large jar, large air-break). There is an impurity of nitrogen in this spectrum. The pair of N lines 4097—4103, which in the ordinary spectrum are very weak where 3995 is strong, are here shown as strong as, or stronger than, 3995. The stronger of the pair is identical with a well-marked stellar line. The stellar counterpart of 4103 is probably masked by strong Hδ.

„ 3.—Spectrum of S.P.O. vacuum tube of nitrogen (8″ coil, disruptive spark, large jar, large air-break), showing the ordinarily-weak N lines 4097—4103 very strongly developed, the former quite as strong as the well-known N line 3995.

„ 4.—Spectrum of Gallenkamp nitrogen vacuum tube (8″ coil, small jar, small air-break), showing 3995 strong, 4097—4103 weak.

„ 5.—Spectrum of S.P.O. vacuum tube of nitrogen (8″ coil, small jar, very small air-break), showing 3995 strong, 4097—4103 lacking.

„ 6.—Spectrum of ε Orionis (region 4340—4450). Directly enlarged 12 times.

„ 7.—Spectrum of Gallenkamp nitrogen vacuum tube (8″ coil, disruptive spark, large jar, large air-break), showing line 4379·8—which is a weak, insignificant line in the ordinary nitrogen spark spectrum—quite as strong as 4447, which is, in the spark spectrum, one of the strongest lines.

„ 8.—Spectrum of Gallenkamp nitrogen vacuum tube (8″ coil, small jar, small air-break), showing 4447 considerably stronger than 4379·8.

„ 9.—Spectrum of Gallenkamp nitrogen vacuum tube (8″ coil, small jar, very small air-break), showing 4447 quite strong, 4379·8 being lacking.

„ 10.—Spark spectrum of chromium (Spottiswoode coil, 42″ spark, large jar, large air-break), showing the four lines 4089, 4097, 4103, 4116 as "beaded" or "pole" lines near the bottom edge of the spectrum. They are indicated by four small arrows just above the "beads." The first and last are silicium (IV) lines, the middle pair abnormal nitrogen lines. The agreement of three of these with well-marked ε Orionis lines (Strip 11) will be seen. The remaining line 4103 is probably masked in the star by the strong Hδ line.

„ 11.—Spectrum of ε Orionis (region 4050—4150). Directly enlarged 7 times.

„ 12.—Spectrum of amidogene vacuum tube (8″ coil, large jar, large air-break), which gives four lines identical in position with the four "pole" lines of the chromium photograph (Strip 10). These amidogene tube lines are seen to agree also in position with lines in ε Orionis. The two silicium lines, 4089, 4116, in this spectrum are due to the presence of detached particles of glass in the bore of the vacuum tube.

„ 13.—Spectrum of S.P.O. vacuum tube of nitrogen (8″ coil, large jar, large air-break), showing the abnormal pair of N lines 4097—4103 identical in position with the middle pair of the four lines given by the amidogene tube (Strip 12).

„ 14.—Spectrum of ε Orionis (region 4550—4670). Directly enlarged 12 times.

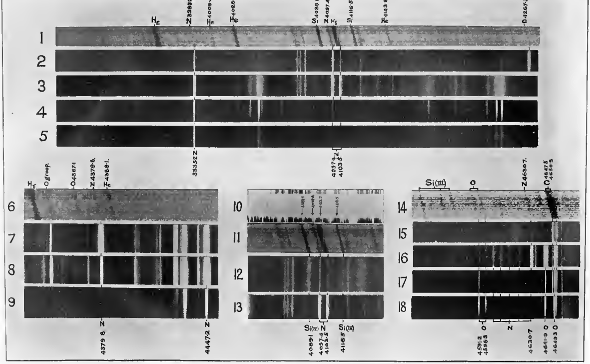
„ 15.—Spectrum of carbon spark in hydrogen (8″ coil, large jar, large air-break), showing strong double at 4647·5—4650·9, probably due to carbon, identical in position with a strong unknown double in ε Orionis (Strip 14). There is in this spectrum a trace of the strong N line 4630·7, which also occurs as a weak line in the stellar spectrum.

„ 16.—Spectrum of alcohol vacuum tube (8″ coil, large jar, large air-break), showing the double carbon line of Strip 14 divided by the oxygen line 4649·3. This spectrum contains nitrogen lines, possibly due to a leakage of air.

„ 17.—Spectrum of SO_2 Gallenkamp vacuum tube (6″ coil, small jar, small air-break), showing the double carbon line of Strip 14, divided by the oxygen line 4649·3. There is evidently an impurity of carbon in this vacuum tube, as the well-known high temperature carbon 4267·3 is very strongly shown in the SO_2 spectrum, but the line is outside the region reproduced in Strip 17.

„ 18.—Spectrum of Gallenkamp oxygen vacuum tube (8″ coil, large jar, large air-break). The line immediately to the right of the strong 4649·3 line is a true oxygen line, but the lines in Strips 16 and 17, which apparently correspond to it, are there much too strong to be accounted for by the oxygen line alone. In those strips the line in question is probably compounded of the oxygen line (4650) and the less refrangible member of the carbon double of Strip 15

SPECTRA SHOWING IDENTIFICATION OF HITHERTO UNKNOWN LINES IN ϵ ORIONIS.



DESCRIPTION OF PLATE 2.

Strip No. 1.—Spectrum of ϵ Orionis (region 3900—4270). Directly enlarged 7 times.

" 2.—Spectrum given by alcohol vacuum tube (8″ coil, disruptive spark, large jar, large air-break). There is an impurity of nitrogen in this spectrum. The pair of N lines 4097—4103, which in the ordinary spectrum are very weak where 3995 is strong, are here shown as strong as, or stronger than, 3995. The stronger of the pair is identical with a well-marked stellar line. The stellar counterpart of 4103 is probably masked by strong $H\delta$.

" 3.—Spectrum of S.P.O. vacuum tube of nitrogen (8″ coil, disruptive spark, large jar, large air-break), showing the ordinarily-weak N lines 4097—4103 very strongly developed, the former quite as strong as the well-known N line 3995.

" 4.—Spectrum of Gallenkamp nitrogen vacuum tube (8″ coil, small jar, small air-break), showing 3995 strong, 4097—4103 weak.

" 5.—Spectrum of S.P.O. vacuum tube of nitrogen (8″ coil, small jar, very small air-break), showing 3995 strong, 4097—4103 lacking.

" 6.—Spectrum of ϵ Orionis (region 4340—4450). Directly enlarged 12 times.

" 7.—Spectrum of Gallenkamp nitrogen vacuum tube (8″ coil, disruptive spark, large jar, large air-break), showing line 4379·8—which is a weak, insignificant line in the ordinary nitrogen spark spectrum—quite as strong as 4447, which is, in the spark spectrum, one of the strongest lines.

" 8.—Spectrum of Gallenkamp nitrogen vacuum tube (8″ coil, small jar, small air-break), showing 4447 considerably stronger than 4379·8.

" 9.—Spectrum of Gallenkamp nitrogen vacuum tube (8″ coil, small jar, very small air-break), showing 4447 quite strong, 4379·8 being lacking.

" 10.—Spark spectrum of chromium (Spottiswoode coil, 42″ spark, large jar, large air-break), showing the four lines 4089, 4097, 4103, 4116 as "beaded" or "pole" lines near the bottom edge of the spectrum. They are indicated by four small arrows just above the "beads." The first and last are silicium (IV) lines, the middle pair abnormal nitrogen lines. The agreement of three of these with well-marked ϵ Orionis lines (Strip 11) will be seen. The remaining line 4103 is probably masked in the star by the strong $H\delta$ line.

" 11.—Spectrum of ϵ Orionis (region 4050—4150). Directly enlarged 7 times.

" 12.—Spectrum of amidogene vacuum tube (8″ coil, large jar, large air-break), which gives four lines identical in position with the four "pole" lines of the chromium photograph (Strip 10). These amidogene tube lines are seen to agree also in position with lines in ϵ Orionis. The two silicium lines, 4089, 4116, in this spectrum are due to the presence of detached particles of glass in the bore of the vacuum tube.

" 13.—Spectrum of S.P.O. vacuum tube of nitrogen (8″ coil, large jar, large air-break), showing the abnormal pair of N lines 4097—4103 identical in position with the middle pair of the four lines given by the amidogene tube (Strip 12).

" 14.—Spectrum of ϵ Orionis (region 4550—4670). Directly enlarged 12 times.

" 15.—Spectrum of carbon spark in hydrogen (8″ coil, large jar, large air-break), showing strong double at 4647·5—4650·9, probably due to carbon, identical in position with a strong unknown double in ϵ Orionis (Strip 14). There is in this spectrum a trace of the strong N line 4630·7, which also occurs as a weak line in the stellar spectrum.

" 16.—Spectrum of alcohol vacuum tube (8″ coil, large jar, large air-break), showing the double carbon line of Strip 14 divided by the oxygen line 4649·3. This spectrum contains nitrogen lines, possibly due to a leakage of air.

" 17.—Spectrum of SO_2 Gallenkamp vacuum tube (8″ coil, small jar, small air-break), showing the double carbon line of Strip 14, divided by the oxygen line 4849·3. There is evidently an impurity of carbon in this vacuum tube, as the well-known high temperature carbon 4267·3 is very strongly shown in the SO_2 spectrum, but the line is outside the region reproduced in Strip 17.

" 18.—Spectrum of Gallenkamp oxygen vacuum tube (8″ coil, large jar, large air-break). The line immediately to the right of the strong 4649·3 is a true oxygen line, but the lines in Strips 16 and 17, which apparently correspond to it, are there much too strong to be accounted for by the oxygen line alone. In those strips the line in question is probably compounded of the oxygen line (4850) and the less refrangible member of the carbon double of Strip 15